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CLAIMS

[Claim(s)]

[Claim 1] In the surface layer property measuring method which measures the property of the surface layer of this analyte from two or more acoustic signals received from analyte The group delay of the frequency of the arbitration between two acoustic signals in said two or more acoustic signals is found. The measuring method of the surface layer property characterized by changing the group delay of the frequency of the arbitration between said two acoustic signals searched for into a surface layer property based on the relation between the group delay found beforehand and said surface layer property, and measuring the property of the surface layer of analyte.

[Claim 2] The measuring method of the surface layer property according to claim 1 characterized by the relation of said group delay and surface layer property which were searched for beforehand being the transform function changed into the property of a surface layer from group delay.

[Claim 3] The measuring method of the surface layer property according to claim 1 or 2 characterized by said surface layer property being hardening layer thickness.

[Claim 4] It is the surface layer property measuring method according to claim 2 which said surface layer property is the depth direction distribution of the physical properties of a surface layer, and is characterized by for the frequencies of said arbitration being two or more frequencies, and being a transform function with which said transform function relates the group delay of two or more of said frequencies, and the depth direction distribution of said physical properties according to the depth direction energy distribution.

[Claim 5] It is the surface layer property measuring method according to claim 2 which said surface layer property is the depth direction distribution of the physical properties of a surface layer, and is characterized by for the frequencies of said arbitration being two or more frequencies, and being a transform function with which said transform function relates the group delay of two or more of said frequencies, and the depth direction distribution of said physical properties according to the depth direction sound pressure distribution.

[Claim 6] said surface layer property -- the depth direction distribution of the physical properties of a surface layer -- it is -- the frequency of plurality [frequency / of said arbitration] -- it is -- said transform function -- the group delay of two or more of said frequencies, and the depth direction distribution of said physical properties -- the depth direction -- a variation rate -- the surface layer property measuring method according to claim 2 characterized by being the transform function associated according to distribution.

[Claim 7] A surface layer property measuring method given in claim 4 characterized by said surface layer property being hardness distribution of a surface layer thru/or any 1 term of 6.

[Claim 8] In the surface layer property measuring device which measures the property of the surface layer of this analyte from two or more acoustic signals received from analyte A group delay operation means to compute the group delay between two acoustic signals of the arbitration which received in a different location among two or more acoustic signals received with a sound reception means to receive the acoustic signal which spreads said analyte front face, and this sound reception means, The surface layer property measuring device characterized by having a surface layer property conversion means to change into the surface layer property of this analyte the group delay calculated with this group delay operation means.

[Claim 9] The surface layer property measuring device according to claim 8 by which it is characterized [which is characterized by said sound reception means coming to contain a means to transmit an acoustic signal].

[Claim 10] The surface layer property measuring device according to claim 8 characterized by said surface layer property conversion means coming to contain the memory in which the relation between hardening layer thickness and group delay was stored, and the arithmetic circuit which calculates hardening layer thickness from said group delay based on said relation memorized by this memory.

[Claim 11] The surface layer property measuring device according to claim 8 characterized by said surface layer property conversion means coming to contain hardening layer thickness, the memory in which the relation of the sonic rate of change to a base material was stored, and the arithmetic circuit which calculates hardening layer

thickness from said group delay based on said relation memorized by this memory.

[Claim 12] The surface layer property measuring device according to claim 8 characterized by said surface layer property conversion means coming to contain the memory in which the hardness of analyte and the relation of group-velocity rate of change were stored, and the arithmetic circuit which calculates the hardness distribution on the front face of analyte from said group-velocity rate of change based on said relation memorized by this memory.

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DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Field of the Invention] This invention relates to the approach and equipment which measure the property of an analyte surface layer by un-destroying using an acoustic signal.

[0002]

[Description of the Prior Art] The method of using sonic change of a surface wave as an approach of measuring the depth direction distribution of the thickness of a surface layer or the properties (hardness etc.) of a surface layer by un-destroying is learned. This approach uses that the acoustical property of a surface layer, i.e., the elastic modulus and consistency of a surface layer, differs from the base material section. That is, the rate that a surface wave spreads the surface layer and the base material section of a surface wave with the thickness of a surface layer since 90% or more of energy exists in the depth direction from the front face of analyte at one wave of within the limits changes. Consequently, it will be said that the acoustic velocity of a surface wave changes according to the thickness of a surface layer.

[0003] There is an approach indicated by JP,62-277554,A as a measuring method using this principle. By this approach, the analyte front face was made to spread a surface wave, it was received by one side, acoustic velocity was searched for from the propagation time in the meantime, and the thickness of a surface layer is measured from the sonic rate of change on the basis of the acoustic velocity of a base material. However, in a surface wave, the phenomenon which the way of a RF spreads according to the distributed phenomenon in which acoustic velocity changes with frequencies, more quickly than low frequency arises, and it changes or spreads with propagation. For this reason, by the above-mentioned approach, highly precise propagation-time measurement is difficult.

[0004] As a means to solve this, there is a method of searching for acoustic velocity from the propagation time for every frequency, and the approach announced by nondestructive inspection (39th volume No. 2 pp. 99 -103) "nondestructive evaluation of the surface layer by the Rayleigh wave" is learned as this example. By this approach, the phase velocity of two or more frequencies is measured, and the depth direction distribution of the elastic modulus of a surface layer is calculated from that rate of change.

[0005]

[Problem(s) to be Solved by the Invention] By the way, although the phase velocity of the wave number is measured two or more rounds with the above-mentioned conventional technique, measurement of the phase time delay between the points receiving [2] is needed for this. About both the received waves received at said point receiving [2], a phase time delay is computed from the phase contrast of a certain frequency component. This process is explained with reference to drawing 10 . In this drawing, the wave of the angular frequency ω in the receiving point 2 presupposes that there is phase lag of θ (ω) to the wave of the angular frequency ω in the receiving point 1. however, ** which the trough A of the receiving point 1 is the trough B of the receiving point 2 in fact, or is trough B' or are other troughs which 2π left ready several times -- it is not clear. That is, the optionality of $2n\pi$ (n is an integer) exists in phase contrast θ (ω), and it is phase contrast θ (ω). $\theta(\omega) = \theta_{\text{etar}} + (\omega) 2n\pi \dots (1)$

It can express. On the other hand, it is phase time delay $\tau_{\text{aup}}(\omega)$. $\tau_{\text{aup}} = (\omega) \theta(\omega) / \omega \dots (2)$

Since it is come out and computed, it is too influenced of the optionality of $2n\pi$. For this reason, it is necessary to solve this problem with another means.

[0006] So, by the well-known example of said latter, where the condition and surface layer of a base material are formed, a means to ask the known acoustic velocity and the known propagation path length of a base material for near phase contrast, and to ask only for the gap between $-\pi$ to π from the phase contrast by measurement from a premise that only the difference within $2n\pi$ is produced in the phase contrast of received waves is adopted.

However, when the case where the location of transmission or reception is unstable, and a propagation path are curved surfaces and measurement of propagation path length is difficult, near precise contrast cannot be known with said means, as a result measurement of the elastic modulus (hardness) of a surface layer becomes difficult. [0007] This invention was made in view of the actual condition of such a conventional technique, and the purpose is in offering the approach and equipment which can measure the property of a surface layer, even if propagation path length is strange.

[0008]

[Means for Solving the Problem] In the surface layer property measuring method with which the 1st means measures the property of the surface layer of this analyte from two or more acoustic signals received from analyte in order to attain the above-mentioned purpose The group delay of the frequency of the arbitration between two acoustic signals in said two or more acoustic signals is found. It is characterized by changing the group delay of the frequency of the arbitration between said two acoustic signals into a surface layer property, and measuring the property of the surface layer of analyte from the relation between the group delay found beforehand and said surface layer property.

[0009] In this case, the transform function changed into the property of a surface layer from group delay is introduced as relation of the property of said group delay and surface layer for which it asked beforehand, and hardening layer thickness is measured as a surface layer property.

[0010] Moreover, when measuring the depth direction distribution of the physical properties of a surface layer as said surface layer property, the frequencies of said arbitration are two or more frequencies, introduce the transform function which associates the group delay of two or more of said frequencies, and the depth direction distribution of said physical properties according to the depth direction energy distribution as said transform function, and measure hardness distribution of a surface layer as a surface layer property.

[0011] Moreover, it can replace with said energy distribution and sound pressure distribution or displacement distribution can also be introduced.

[0012] In the surface layer property measuring device with which the 2nd means measures the property of the surface layer of this analyte from two or more acoustic signals received from analyte A group delay operation means to compute the group delay between two acoustic signals of the arbitration which received in a different location among two or more acoustic signals received with a sound reception means to receive the acoustic signal which spreads said analyte front face, and this sound reception means, It is characterized by having a surface layer property conversion means to change into the surface layer property of this analyte the group delay calculated with this group delay operation means.

[0013] In this case, it can also constitute so that said sound reception means may serve as both functions including a means to transmit an acoustic signal.

[0014] Moreover, the related storage section by which said surface layer property conversion means was stored in the relation between hardening layer thickness and group delay, The related storage section in which hardening layer thickness and the relation of sonic rate of change [as opposed to a base material in constituting including the arithmetic circuit which calculates hardening layer thickness from said group delay based on said relation memorized by this related storage section ****] were stored, The related storage section in which it constituted including the arithmetic circuit which calculates hardening layer thickness from said group delay based on said relation memorized by this related storage section, or the hardness of analyte and the relation of group-velocity rate of change were stored, Based on said relation memorized by this related storage section, it can constitute from said group delay including the arithmetic circuit which calculates the hardness distribution on the front face of analyte, respectively.

[0015] Thus, if constituted, since group delay is the value which differentiated the phase with angular frequency, it can be computed regardless of the optionality of 2π of a phase. It becomes unnecessary to introduce the solution means of measuring propagation path length by this.

[0016] Moreover, since the depth direction energy distribution is known when it is the formula which associates the depth direction distribution of the relative group delay of two or more frequencies, and relative group velocity for the change function which searches for a surface layer property according to the depth direction energy distribution of an acoustic signal, and the function which associates group-velocity rate of change and the physical-properties value of a surface layer, the depth direction distribution of relative group velocity is computable with the inverse transformation of this formula. Relative group velocity can compute the group-velocity rate of change to the base material group velocity of each class in accordance with the group velocity of a base material by the deepest part of the depth direction. Next, this group-velocity rate of change is changed into the physical-properties value of a surface layer based on said relation. in addition, that it can be with relativity here, it is one (propagation path length is not used for count) with strange propagation path length, and is because the rate itself is not necessarily computed.

[0017]

[Example] Hereafter, 1 operation of this invention is explained with reference to a drawing.

[0018] The mode of propagation uses the supersonic wave of a surface wave at drawing 1, and the outline configuration of the surface layer property measuring device which measures the property of the hardening layer formed in the steel-materials front face is shown.

[0019] Layer thickness measurement equipment is equipped with a receiver 1, a receiver 2, the sound receive section 3, a digitizer 4, the group delay operation part 5, the surface layer property operation part 6, and the output section 7 in this drawing.

[0020] In drawing 1, among the surface waves which spread the field where the hardening layer 11 was formed in the front face of steel materials 10, a receiver 1 receives the supersonic wave 8 refracted in the receiver 1 side concerned, and the receiver 2 left and arranged from the receiver 1 receives the supersonic wave 9 refracted in the receiver 2 side concerned. A supersonic wave 8 and a supersonic wave 9 are changed into an electrical signal, and are respectively changed into wave $x(t)$ of a digital signal, and $y(t)$ with the digitizer 4 which is amplified in the sound receive section 3 which consists of ultrasonic flow detectors etc., and consists of digital oscilloscopes etc. In a digitizer 4, this digital signal is held from a certain time of day about a supersonic wave 8 as wave $x(t)$ of the digital signal of the time amount section (a "time window" is called hereafter) of constant width, and is held about a supersonic wave 9 as wave $y(t)$ of the digital signal of the time window which begins from the time of day which may differ from $x(t)$. In addition, although an operator may specify logging of a time window, as long as the near time amount in which a supersonic wave 8 and a supersonic wave 9 appear is known, the time window which fixed the time delay beforehand may be prepared.

[0021] In the group delay operation part 5, group delay $\tau_U(\omega)$ (ω is the angular frequency of a supersonic wave) of two or more round wave number of said wave $x(t)$ and wave $y(t)$ is calculated, and the property of a surface layer is calculated by the surface layer property operation part 6. The calculated result is outputted in the output section 7. Moreover, the logging location and width of face of a time window are inputted from the input section 12. In addition, the same receiver is satisfactory for a receiver 1 and a receive section 2. However, it is necessary to change the location of a receiver and to receive a surface wave in that case, in a different location.

[0022] The example of 1 configuration of the group delay operation part 5 and the function of each part are explained with reference to drawing 2. A control circuit 501 reads wave $x(t)$ as controlled the change-over machine 502 and shown in drawing 3 from a digitizer 4, and wave $y(t)$, and memorizes them in the wave $x(t)$ memory 503 and the wave $y(t)$ memory 504, respectively. Next, a control circuit 501 controls the change-over machine 505, reads a wave and makes the fourier converter 506 carry out the Fourier transform of the wave $y(t)$ for a wave to wave $x(t)$ by delivery and the fourier converter 506 from the wave $x(t)$ memory 503 and the wave $y(t)$ memory 504. Wave $x(t)$ by which the Fourier transform was carried out, and $y(t)$ are respectively memorized by the $X(\omega)$ memory 508 and the $Y(\omega)$ memory 509 which are further chosen with the change-over vessel 507 controlled by the control circuit 501. Next, based on the data point memorized by the $X(\omega)$ memory 508 and the $Y(\omega)$ memory 509, the cross spectrum of $X(\omega)$ and $Y(\omega)$ is computed with the cross-spectrum computing element 510, and the result of an operation is memorized in the $Z(\omega)$ memory 511. In addition, the $X(\omega)$ memory 508, the $Y(\omega)$ memory 509, and the $Z(\omega)$ memory 511 consist of real number memory and imaginary memory, respectively. The cross spectrum memorized by the $Z(\omega)$ memory 511 is inputted phase characteristic computing-element 512, and the phase characteristic $\theta(\omega)$ of a cross spectrum (ω) (refer to drawing 3) is computed. The computed migration property $\theta(\omega)$ is differentiated with the phase differentiator 513, and a time delay is found. The propagation-time adder 514 adds time delay τ_{window} between the time delay found with the phase differentiator 513, and the time window read from the wave **** condition memory 515. Group delay $\tau_U(\omega)$ [as a result of being added] $\tau_U(\omega)$ is sent to the surface layer property operation part 6.

[0023] Procedure which asks for group delay $\tau_U(\omega)$ from the phase characteristic $\theta(\omega)$ of a cross spectrum (ω) in the above function $\tau_U(\omega) = \theta(\omega) / d\theta(\omega) / d\omega + \tau_{window} \dots (3)$ It is come out and expressed. This formula (3) shows that it can be computed even if group delay $\tau_U(\omega)$ has the optionality of $2\pi n\pi$ in the phase $\theta(\omega)$ of a cross spectrum (ω), since said $2\pi n\pi$ is not contained as an element.

[0024] The surface layer property operation part 6 has an arithmetic circuit 61 and memory 62, as shown in drawing 4. This example is an example which measures the thickness of a hardening layer as a property of a hardening layer. Hardening layer thickness and the relation of group delay are beforehand stored in said memory 62. As an example of this relation, artificers show the example of the experimental result which performed distance of a receiver 1 and a receiver 2 as about 57mm to the bottom of the equipment configuration of drawing 1 to drawing 5. This drawing shows hardening layer thickness and the relation of the group delay of a 4.8MHz

surface wave, and group delay is short in this drawing, so that hardening layer thickness becomes thick. That is, it turns out that group velocity is in the relation which becomes so quick that hardening layer thickness is thick. From this, it can ask for this relation using the test piece whose thickness is two or more known kinds, and can ask for hardening layer thickness from group delay conversely by using as a calibration curve. In addition, the hardening layer thickness and the relation of group delay which are memorized in memory 62 are memorized about the wave number two or more rounds, and refer to the relation of a required frequency for them from memory 62. As for the frequency at this time, it is desirable to consider as the frequency which is extent the thickness of a hardening layer and whose order of wavelength correspond, and to use a probe with the large amplitude of that frequency region.

[0025] In addition, the relation between hardening layer thickness and the sonic rate of change to a base material is sufficient as the data memorized in memory 62. Moreover, three or more receivers may be prepared, the group delay of the supersonic wave received with two receivers of arbitration may be found, and same processing may be performed.

[0026] Thus, since group delay $\tau_U(\omega)$ computed from a formula (3) is changed into the property of a surface layer with this operation. Even if the optionality of $2n\pi$ is in the phase θ of a cross spectrum (ω), are computable. The need of calculating the value of n of $2n\pi$ of a phase like the above-mentioned phase time delay by this, The function which measures correctly, the measurement conditions, for example, the propagation path length, of a phase time delay, measurement conditions where the condition and surface layer of a base material are formed, that only the difference within $2n\pi$ is produced in the phase contrast of received waves, etc. become unnecessary, and a measurement process and an equipment configuration can be simplified.

[0027] Here, the contents of concrete processing when measuring the property (thickness) of the hardening layer of the arithmetic circuit 61 of the surface layer property operation part 6 are explained. Drawing 6 is a flow chart which shows processing of the surface layer property operation part 6, and the relation of data flow.

[0028] In this processing, group delay $\tau_U(\omega)$ is read from the group delay operation part 5 at step 611 after processing initiation, further, the thickness of a hardening layer and the relation of group delay are read from memory (related storage section) 62, and group delay is changed into thickness from this relation. Subsequently, the thickness of the hardening layer changed from group delay τ_U at step 612 (ω) is outputted to the output section 7, and it asks that it is processing termination at step 613, and if it is not termination, it will return to step 611. In addition, the thickness of a hardening layer and the relation of sonic rate of change are sufficient as the data read from memory (related storage section) 62 at step 611.

[0029] Next, an approach with it is explained. [effective when the hardness of a hardening layer approaches the hardness of a base material continuously (a hardening layer actually shows such a property in many cases)]

[0030] The surface layer property operation part 6 shown in drawing 4 can be constituted as follows, when measuring the depth direction distribution of a hardening layer as a property of a hardening layer. That is, the relation between hardness as shown in drawing 7, and group-velocity rate of change is stored in memory 62. Hardness needs to measure this relation beforehand using a known test piece etc. Moreover, an arithmetic circuit 61 has the calculation function which changes group-velocity rate of change into hardness.

[0031] Here, the example of concrete processing in an arithmetic circuit 61 is explained. Drawing 8 is a flow chart which shows processing and data flow of an arithmetic circuit 61. Group delay $\tau_U(k(\omega_k)) = 1/n$ of two or more round wave number of n pieces is read from the group delay operation part 5 at step 614 after processing initiation. It divides into the false layer for count near the front face of analyte (a "count layer" is called hereafter) here, and is U_n from U_1 from the shallower one to order about the group velocity of each class. It sets. Here, a count layer is assumed to the depth from which the hardness of a hardening layer becomes equivalent to the hardness of a base material. As for the energy distribution of a surface wave, 90% or more of energy is distributed over one wave of within the limits under a front face, and it is known theoretically that the energy distribution will change exponentially (elastic wave theory PAGA88 written by Yasuo Sato). for this reason, the group velocity V of a certain wavelength (ω) -- energy distribution P_k of each count layer Group velocity U_k from -- weight -- if it assumes that it is computable on the average $V(\omega_k) = \sum (P_k U_k) \dots (4)$

($\sum P_k = 1$ [however,]) is materialized. In addition, sound pressure distribution, displacement distribution, etc. may be used instead of energy distribution. If a formula (4) is expressed about a total-session layer $V = PU \dots (5)$ It is expressed. $n \times 1$ matrix and U to which V expresses the group velocity of angular-frequency ω_k ($k=1-n$) here are the count layer k ($k=1-n$) ($n \times 1$ matrix showing group velocity and P are the $n \times n$ matrices showing the energy distribution of angular-frequency ω_k ($k=1-n$)). Energy distribution P will be the group velocity U of a count layer, if the group velocity V of angular-frequency ω_k ($k=1-n$) is measured from the theory, since it is known. $U = P^{-1}V \dots (6)$

It comes out and asks.

[0032] However, since the propagation distance L has not measured correctly here, the group velocity V of each

frequency contains the strange multiplier L . Therefore, it depends for the group velocity U of a count layer on the strange multiplier L . However, since we can presume that the deepest count layer n in a count layer shows a group velocity comparable as a base material, group-velocity rate of change is calculated as a value by the strange multiplier L using the group velocity U_n here. Group-velocity rate of change of each count layer (%) $\{(U_k - U_n) / U_n\} * 100 \dots (7)$

It is given by (however, $k=1-n$).

[0033] In the above procedure, group-velocity rate-of-change distribution of the depth direction is computed at step 614. Next, at step 615, the relation between group-velocity rate of change and hardness is read from memory (related storage section) 62, and group-velocity rate of change is changed into hardness. And hardening layer thickness is outputted to the output section 7 at step 616, and it asks that it is processing termination at step 617, and if it is not termination, it will return to step 614.

[0034] Here, although hardness distribution was searched for, if even the threshold hardness is defined as a hardening layer by making a certain hardness into a threshold, in step 615, it can ask for hardening layer thickness easily from hardness distribution.

[0035] Thus, according to this operation gestalt, since group-velocity rate-of-change distribution of the depth direction is searched for for the group velocity of the deepest count layer as criteria (group velocity of a base material) for every measurement, a probe can be arranged in the distance of arbitration for every measurement. Therefore, with the irregularity on the front face of analyte, when the location of the probe index to the analyte of an acoustic signal or an outgoing radiation point is unstable, or when a propagation path is a curved surface, measurement becomes possible.

[0036] In addition, in the above-mentioned operation gestalt, although the property of a surface layer was explained as the thickness of a surface layer, or hardness distribution of a surface layer, if it is the property which has group-velocity rate of change, such as a consistency, an elastic modulus, and residual stress, and correlation other than hardness in the rate of change of group velocity since it is the approach of evaluating a property secondarily as an index, it is theoretically measurable in the property by the same approach and equipment.

[0037] Next, other operation gestalten are explained. This operation gestalt is an example in the case of making an analyte front face generate a surface wave actively, and shows that outline configuration to drawing 9.

[0038] Layer thickness measurement equipment is equipped with transceiver machine 1a, a receiver 2, sound transceiver section 3a, a digitizer 4, the group delay operation part 5, the surface layer property operation part 6, and the output section 7 in this drawing. With this layer thickness measurement equipment, transceiver machine 1a to ultrasonic 8a is transmitted in response to the transmitted pulse from sound transceiver section 3a which consists of ultrasonic flow detectors etc. Mode transformation of the ultrasonic 8a is carried out to a surface wave in an interface with steel materials 10, and it reflects at the edge of a wedge 12, and the surface wave which carried out mode transformation is divided into ultrasonic 8b again refracted in a wedge, and the supersonic wave 9 which passes through an edge and is received with another receiver 2, receives these, respectively, and is similarly processed by the same each part as the above-mentioned operation gestalt.

[0039] Thus, since it becomes unnecessary to newly prepare a sound transmitter when constituted, an equipment configuration can be simplified.

[0040]

[Effect of the Invention] Since the approach, the function, or the measurement conditions of calculating the value of n of $2\pi n$ of a phase like a phase time delay become unnecessary according to this invention, a measurement process and an equipment configuration can be simplified.

[0041] Moreover, according to this invention, a probe can be arranged in the distance of arbitration for every measurement. Therefore, with the irregularity on the front face of analyte, when the location of the outgoing radiation point of the probe index to the analyte of an acoustic signal is unstable, or when a propagation path is a curved surface, measurement becomes possible.

[0042] Furthermore, according to this invention, even when it is necessary to make an analyte front face generate a surface wave actively, it is not necessary to newly prepare a sound transmitter, and an equipment configuration becomes easy.

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TECHNICAL FIELD

[Field of the Invention] This invention relates to the approach and equipment which measure the property of an analyte surface layer by un-destroying using an acoustic signal.

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PRIOR ART

[Description of the Prior Art] The method of using sonic change of a surface wave as an approach of measuring the depth direction distribution of the thickness of a surface layer or the properties (hardness etc.) of a surface layer by un-destroying is learned. This approach uses that the acoustical property of a surface layer, i.e., the elastic modulus and consistency of a surface layer, differs from the base material section. That is, the rate that a surface wave spreads the surface layer and the base material section of a surface wave with the thickness of a surface layer since 90% or more of energy exists in the depth direction from the front face of analyte at one wave of within the limits changes. Consequently, it will be said that the acoustic velocity of a surface wave changes according to the thickness of a surface layer.

[0003] There is an approach indicated by JP,62-277554,A as a measuring method using this principle. By this approach, the analyte front face was made to spread a surface wave, it was received by one side, acoustic velocity was searched for from the propagation time in the meantime, and the thickness of a surface layer is measured from the sonic rate of change on the basis of the acoustic velocity of a base material. However, in a surface wave, the phenomenon which the way of a RF spreads according to the distributed phenomenon in which acoustic velocity changes with frequencies, more quickly than low frequency arises, and it changes or spreads with propagation. For this reason, by the above-mentioned approach, highly precise propagation-time measurement is difficult.

[0004] As a means to solve this, there is a method of searching for acoustic velocity from the propagation time for every frequency, and the approach announced by nondestructive inspection (39th volume No. 2 pp. 99 -103) "nondestructive evaluation of the surface layer by the Rayleigh wave" is learned as this example. By this approach, the phase velocity of two or more frequencies is measured, and the depth direction distribution of the elastic modulus of a surface layer is calculated from that rate of change.

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EFFECT OF THE INVENTION

[Effect of the Invention] Since the approach, the function, or the measurement conditions of calculating the value of n of 2π of a phase like a phase time delay become unnecessary according to this invention, a measurement process and an equipment configuration can be simplified.

[0041] Moreover, according to this invention, a probe can be arranged in the distance of arbitration for every measurement. Therefore, with the irregularity on the front face of analyte, when the location of the outgoing radiation point of the probe index to the analyte of an acoustic signal is unstable, or when a propagation path is a curved surface, measurement becomes possible.

[0042] Furthermore, according to this invention, even when it is necessary to make an analyte front face generate a surface wave actively, it is not necessary to newly prepare a sound transmitter, and an equipment configuration becomes easy.

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TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention] By the way, although the phase velocity of the wave number is measured two or more rounds with the above-mentioned conventional technique, measurement of the phase time delay between the points receiving [2] is needed for this. About both the received waves received at said point receiving [2], a phase time delay is computed from the phase contrast of a certain frequency component. This process is explained with reference to drawing 10 . In this drawing, the wave of the angular frequency ω in the receiving point 2 presupposes that there is phase lag of θ (ω) to the wave of the angular frequency ω in the receiving point 1. however, ** which the trough A of the receiving point 1 is the trough B of the receiving point 2 in fact, or is trough B' or are other troughs which 2π left ready several times -- it is not clear. That is, the optionality of $2n\pi$ (n is an integer) exists in phase contrast θ (ω), and it is phase contrast θ (ω). $\theta(\omega) = \theta + (\omega) 2n\pi \dots (1)$
It can express. On the other hand, it is phase time delay $\tau_p(\omega)$. $\tau_p = (\omega) \theta(\omega) / \omega \dots (2)$

Since it is come out and computed, it is too influenced of the optionality of $2n\pi$. For this reason, it is necessary to solve this problem with another means.

[0006] So, by the well-known example of said latter, where the condition and surface layer of a base material are formed, a means to ask the known acoustic velocity and the known propagation path length of a base material for near phase contrast, and to ask only for the gap between $-\pi$ to π from the phase contrast by measurement from a premise that only the difference within $2n\pi$ is produced in the phase contrast of received waves is adopted.

However, when the case where the location of transmission or reception is unstable, and a propagation path are curved surfaces and measurement of propagation path length is difficult, near phase contrast cannot be known with said means, as a result measurement of the elastic modulus (hardness) of a surface layer becomes difficult.

[0007] This invention was made in view of the actual condition of such a conventional technique, and the purpose is in offering the approach and equipment which can measure the property of a surface layer, even if propagation path length is strange.

[Translation done.]

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MEANS

[Means for Solving the Problem] In the surface layer property measuring method with which the 1st means measures the property of the surface layer of this analyte from two or more acoustic signals received from analyte in order to attain the above-mentioned purpose The group delay of the frequency of the arbitration between two acoustic signals in said two or more acoustic signals is found. It is characterized by changing the group delay of the frequency of the arbitration between said two acoustic signals into a surface layer property, and measuring the property of the surface layer of analyte from the relation between the group delay found beforehand and said surface layer property.

[0009] In this case, the transform function changed into the property of a surface layer from group delay is introduced as relation of the property of said group delay and surface layer for which it asked beforehand, and hardening layer thickness is measured as a surface layer property.

[0010] Moreover, when measuring the depth direction distribution of the physical properties of a surface layer as said surface layer property, the frequencies of said arbitration are two or more frequencies, introduce the transform function which associates the group delay of two or more of said frequencies, and the depth direction distribution of said physical properties according to the depth direction energy distribution as said transform function, and measure hardness distribution of a surface layer as a surface layer property.

[0011] Moreover, it can replace with said energy distribution and sound pressure distribution or displacement distribution can also be introduced.

[0012] This invention is characterized by the surface layer property measuring device with which the 2nd means measures the property of the surface layer of this analyte from two or more acoustic signals received from analyte possessing the following. A sound reception means to receive the acoustic signal which spreads said analyte front face A group delay operation means to compute the group delay between two acoustic signals of the arbitration which received in a different location among two or more acoustic signals received with this sound reception means A surface layer property conversion means to change into the surface layer property of this analyte the group delay calculated with this group delay operation means

[0013] In this case, it can also constitute so that said sound reception means may serve as both functions including a means to transmit an acoustic signal.

[0014] Moreover, the related storage section by which said surface layer property conversion means was stored in the relation between hardening layer thickness and group delay, The related storage section in which hardening layer thickness and the relation of sonic rate of change [as opposed to a base material in constituting including the arithmetic circuit which calculates hardening layer thickness from said group delay based on said relation memorized by this related storage section ****] were stored, The related storage section in which it constituted including the arithmetic circuit which calculates hardening layer thickness from said group delay based on said relation memorized by this related storage section, or the hardness of analyte and the relation of group-velocity rate of change were stored, Based on said relation memorized by this related storage section, it can constitute from said group delay including the arithmetic circuit which calculates the hardness distribution on the front face of analyte, respectively.

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EXAMPLE

[Example] Hereafter, 1 operation gestalt of this invention is explained with reference to a drawing.

[0018] The mode of propagation uses the supersonic wave of a surface wave at drawing 1 , and the outline configuration of the surface layer property measuring device which measures the property of the hardening layer formed in the steel-materials front face is shown.

[0019] Layer thickness measurement equipment is equipped with a receiver 1, a receiver 2, the sound receive section 3, a digitizer 4, the group delay operation part 5, the surface layer property operation part 6, and the output section 7 in this drawing.

[0020] In drawing 1 , among the surface waves which spread the field where the hardening layer 11 was formed in the front face of steel materials 10, a receiver 1 receives the supersonic wave 8 refracted in the receiver 1 side. concerned, and the receiver 2 left and arranged from the receiver 1 receives the supersonic wave 9 refracted in the receiver 2 side concerned. A supersonic wave 8 and a supersonic wave 9 are changed into an electrical signal, and are respectively changed into wave $x(t)$ of a digital signal, and $y(t)$ with the digitizer 4 which is amplified in the sound receive section 3 which consists of ultrasonic flow detectors etc., and consists of digital oscilloscopes etc. In a digitizer 4, this digital signal is held from a certain time of day about a supersonic wave 8 as wave $x(t)$ of the digital signal of the time amount section (a "time window" is called hereafter) of constant width, and is held about a supersonic wave 9 as wave [of the digital signal of the time window which begins from the time of day which may differ from $x(t)$] $y(t)$. In addition, although an operator may specify logging of a time window, as long as the near time amount in which a supersonic wave 8 and a supersonic wave 9 appear is known, the time window which fixed the time delay beforehand may be prepared.

[0021] In the group delay operation part 5, group delay $\tau_U(\omega)$ (ω (omega) is the angular frequency of a supersonic wave) of two or more round wave number of said wave $x(t)$ and wave $y(t)$ is calculated, and the property of a surface layer is calculated by the surface layer property operation part 6. The calculated result is outputted in the output section 7. Moreover, the logging location and width of face of a time window are inputted from the input section 12. In addition, the same receiver is satisfactory for a receiver 1 and a receive section 2. However, it is necessary to change the location of a receiver and to receive a surface wave in that case, in a different location.

[0022] The example of 1 configuration of the group delay operation part 5 and the function of each part are explained with reference to drawing 2 . A control circuit 501 reads wave $x(t)$ as controlled the change-over machine 502 and shown in drawing 3 from a digitizer 4, and wave $y(t)$, and memorizes them in the wave $x(t)$ memory 503 and the wave $y(t)$ memory 504, respectively. Next, a control circuit 501 controls the change-over machine 505, reads a wave and makes the fourier converter 506 carry out the Fourier transform of the wave $y(t)$ for a wave to wave $x(t)$ by delivery and the fourier converter 506 from the wave $x(t)$ memory 503 and the wave $y(t)$ memory 504. Wave $x(t)$ by which the Fourier transform was carried out, and $y(t)$ are respectively memorized by the $X(\omega)$ memory 508 and the $Y(\omega)$ memory 509 which are further chosen with the change-over vessel 507 controlled by the control circuit 501. Next, based on the data point memorized by the $X(\omega)$ memory 508 and the $Y(\omega)$ memory 509, the cross spectrum of $X(\omega)$ and $Y(\omega)$ is computed with the cross-spectrum computing element 510, and the result of an operation is memorized in the $Z(\omega)$ memory 511. In addition, the $X(\omega)$ memory 508, the $Y(\omega)$ memory 509, and the $Z(\omega)$ memory 511 consist of real number memory and imaginary memory, respectively. The cross spectrum memorized by the $Z(\omega)$ memory 511 is inputted phase characteristic computing-element 512, and the phase characteristic $\theta(\omega)$ of a cross spectrum (ω) (refer to drawing 3) is computed. The computed migration property $\theta(\omega)$ is differentiated with the phase differentiator 513, and a time delay is found. The propagation-time adder 514 adds time delay τ_{window} between the time delay found with the phase differentiator 513, and the time window read from the wave **** condition memory 515. Group delay [as a result of being added] $\tau_U(\omega)$ is sent to the surface layer property operation part 6.

[0023] Procedure which asks for group delay $\tau_U(\omega)$ from the phase characteristic θ of a cross spectrum (ω) in the above function $\tau_U(\omega) = (\omega) d\theta(\omega)/d\omega$... (3)

It is come out and expressed. This formula (3) shows that it can be computed even if group delay $\tau_U(\omega)$ has the optionality of $2n\pi$ in the phase θ of a cross spectrum (ω), since said $2n\pi$ is not contained as an element.

[0024] The surface layer property operation part 6 has an arithmetic circuit 61 and memory 62, as shown in drawing 4. This example is an example which measures the thickness of a hardening layer as a property of a hardening layer. Hardening layer thickness and the relation of group delay are beforehand stored in said memory 62. As an example of this relation, artificers show the example of the experimental result which performed distance of a receiver 1 and a receiver 2 as about 57mm to the bottom of the equipment configuration of drawing 1 to drawing 5. This drawing shows hardening layer thickness and the relation of the group delay of a 4.8MHz surface wave, and group delay is short in this drawing, so that hardening layer thickness becomes thick. That is, it turns out that group velocity is in the inclination which becomes so quick that hardening layer thickness is thick. From this, it can ask for this relation using the test piece whose thickness is two or more known kinds, and can ask for hardening layer thickness from group delay conversely by using as a calibration curve. In addition, the hardening layer thickness and the relation of group delay which are memorized in memory 62 are memorized about the wave number two or more rounds, and refer to the relation of a required frequency for them from memory 62. As for the frequency at this time, it is desirable to consider as the frequency which is extent the thickness of a hardening layer and whose order of wavelength correspond, and to use a probe with the large amplitude of that frequency region.

[0025] In addition, the relation between hardening layer thickness and the sonic rate of change to a base material is sufficient as the data memorized in memory 62. Moreover, three or more receivers may be prepared, the group delay of the supersonic wave received with two receivers of arbitration may be found, and same processing may be performed.

[0026] Thus, since group delay $\tau_U(\omega)$ computed from a formula (3) is changed into the property of a surface layer with this operation gestalt Even if the optionality of $2n\pi$ is in the phase θ of a cross spectrum (ω), are computable. The need of calculating the value of n of $2n\pi$ of a phase like the above-mentioned phase time delay by this, The function which measures correctly, the measurement conditions, for example, the propagation path length, of a phase time delay, measurement conditions where the condition and surface layer of a base material are formed, that only the difference within $2n\pi$ is produced in the phase contrast of received waves, etc. become unnecessary, and a measurement process and an equipment configuration can be simplified.

[0027] Here, the contents of concrete processing when measuring the property (thickness) of the hardening layer of the arithmetic circuit 61 of the surface layer property operation part 6 are explained. Drawing 6 is a flow chart which shows processing of the surface layer property operation part 6, and the relation of data flow.

[0028] In this processing, group delay $\tau_U(\omega)$ is read from the group delay operation part 5 at step 611 after processing initiation, further, the thickness of a hardening layer and the relation of group delay are read from memory (related storage section) 62, and group delay is changed into thickness from this relation. Subsequently, the thickness of the hardening layer changed from group delay τ_U at step 612 (ω) is outputted to the output section 7, and it asks that it is processing termination at step 613, and if it is not termination, it will return to step 611. In addition, the thickness of a hardening layer and the relation of sonic rate of change are sufficient as the data read from memory (related storage section) 62 at step 611.

[0029] Next, an approach with it is explained. [effective when the hardness of a hardening layer approaches the hardness of a base material continuously (a hardening layer actually shows such a property in many cases)]

[0030] The surface layer property operation part 6 shown in drawing 4 can be constituted as follows, when measuring the depth direction distribution of a hardening layer as a property of a hardening layer. That is, the relation between hardness as shown in drawing 7, and group-velocity rate of change is stored in memory 62. Hardness needs to measure this relation beforehand using a known test piece etc. Moreover, an arithmetic circuit 61 has the calculation function which changes group-velocity rate of change into hardness.

[0031] Here, the example of concrete processing in an arithmetic circuit 61 is explained. Drawing 8 is a flow chart which shows processing and data flow of an arithmetic circuit 61. Group delay $\tau_U(k(\omega)k) = 1-n$ of two or more round wave number of n pieces is read from the group delay operation part 5 at step 614 after processing initiation. It divides into the false layer for count near the front face of analyte (a "count layer" is called hereafter) here, and is U_n from U_1 from the shallower one to order about the group velocity of each class. It sets. Here, a count layer is assumed to the depth from which the hardness of a hardening layer becomes equivalent to the hardness of a base material. As for the energy distribution of a surface wave, 90% or more of energy is distributed over one wave of within the limits under a front face, and it is known theoretically that the energy distribution will change exponentially (elastic wave theory PAGA88 written by Yasuo Sato). for this reason, the

group velocity V of a certain wavelength (ω) — energy distribution P_k of n count layer Group velocity U_k from — weight — if it assumes that is computable on the average $V(\omega_k) = \sum (P_k U_k) \dots (4)$ ($\sum P_k = 1$ [however,]) is materialized. In addition, sound pressure distribution, displacement distribution, etc. may be used instead of energy distribution. If a formula (4) is expressed about a total-session layer $V = PU \dots (5)$ It is expressed. $n \times 1$ matrix and U to which V expresses the group velocity of angular-frequency ω_k ($k=1-n$) here are the count layer k ($k=1-n$) ($n \times 1$ matrix showing group velocity and P are the $n \times n$ matrices showing the energy distribution of angular-frequency ω_k ($k=1-n$)). Energy distribution P will be the group velocity U of a count layer, if the group velocity V of angular-frequency ω_k ($k=1-n$) is measured from the theory, since it is known. $U = P^{-1}V \dots (6)$

It comes out and asks.

[0032] However, since the propagation distance L has not measured correctly here, the group velocity V of each frequency contains the strange multiplier L . Therefore, it depends for the group velocity U of a count layer on the strange multiplier L . However, since it can presume that the deepest count layer n in a count layer shows a group velocity comparable as a base material, group-velocity rate of change is calculated as a value by the strange multiplier L using the group velocity U_n here. Group-velocity rate of change of each count layer (%) $\{(U_k - U_n) / U_n\} \times 100 \dots (7)$

It is given by (however, $k=1-n$).

[0033] In the above procedure, group-velocity rate-of-change distribution of the depth direction is computed at step 614. Next, at step 615, the relation between group-velocity rate of change and hardness is read from memory (related storage section) 62, and group-velocity rate of change is changed into hardness. And hardening layer thickness is outputted to the output section 7 at step 616, and it asks that it is processing termination at step 617, and if it is not termination, it will return to step 614.

[0034] Here, although hardness distribution was searched for, if even the threshold hardness is defined as a hardening layer by making a certain hardness into a threshold, in step 615, it can ask for hardening layer thickness easily from hardness distribution.

[0035] Thus, according to this operation gestalt, since group-velocity rate-of-change distribution of the depth direction is searched for for the group velocity of the deepest count layer as criteria (group velocity of a base material) for every measurement, a probe can be arranged in the distance of arbitration for every measurement. Therefore, with the irregularity on the front face of analyte, when the location of the probe index to the analyte of an acoustic signal or an outgoing radiation point is unstable, or when a propagation path is a curved surface, measurement becomes possible.

[0036] In addition, in the above-mentioned operation gestalt, although the property of a surface layer was explained as the thickness of a surface layer, or hardness distribution of a surface layer, if it is the property which has group-velocity rate of change, such as a consistency, an elastic modulus, and residual stress, and correlation other than hardness in the rate of change of group velocity since it is the approach of evaluating a property secondarily as an index, it is theoretically measurable in the property by the same approach and equipment.

[0037] Next, other operation gestalten are explained. This operation gestalt is an example in the case of making an analyte front face generate a surface wave actively, and shows that outline configuration to drawing 9.

[0038] Layer thickness measurement equipment is equipped with transceiver machine 1a, a receiver 2, sound transceiver section 3a, a digitizer 4, the group delay operation part 5, the surface layer property operation part 6, and the output section 7 in this drawing. With this layer thickness measurement equipment, transceiver machine 1a to ultrasonic 8a is transmitted in response to the transmitted pulse from sound transceiver section 3a which consists of ultrasonic flow detectors etc. Mode transformation of the ultrasonic 8a is carried out to a surface wave in an interface with steel materials 10, and it reflects at the edge of a wedge 12, and the surface wave which carried out mode transformation is divided into ultrasonic 8b again refracted in a wedge, and the supersonic wave 9 which passes through an edge and is received with another receiver 2, receives these, respectively, and is similarly processed by the same each part as the above-mentioned operation gestalt.

[0039] Thus, since it becomes unnecessary to newly prepare a sound transmitter when constituted, an equipment configuration can be simplified.

[Translation done.]

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DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]

[Drawing 1] It is the outline block diagram of the measuring device of the surface layer property concerning the operation gestalt of this invention.

[Drawing 2] It is the block diagram showing the configuration of the group delay operation part in drawing 1.

[Drawing 3] It is the explanatory view showing the computation of the group delay in the group delay operation part in drawing 1.

[Drawing 4] It is the block diagram showing the configuration of the surface layer property operation part in drawing 1.

[Drawing 5] It is the explanatory view showing change of the group delay over hardening layer thickness.

[Drawing 6] It is the flow chart which shows the procedure of the surface layer property operation part in drawing 4.

[Drawing 7] It is the explanatory view showing change of the group-velocity rate of change to hardness.

[Drawing 8] It is the flow chart which shows other procedure of the surface layer property operation part in drawing 4.

[Drawing 9] It is the outline block diagram of the measuring device of the surface layer property concerning other operation gestalten of this invention.

[Drawing 10] It is the explanatory view showing the optionality of 2npi of a phase time delay.

[Description of Notations]

- 1 Receiver
- 2 Receiver
- 3 Sound Receive Section
- 4 Digitizer
- 5 Group Delay Operation Part
- 6 Surface Layer Property Operation Part
- 7 Output Section
- 8 Supersonic Wave
- 9 Supersonic Wave
- 10 Steel Materials
- 11 Hardening Layer
- 12 Input Section
- 61 Arithmetic Circuit
- 62 Memory (Related Storage Section)

[Translation done.]

* NOTICES *

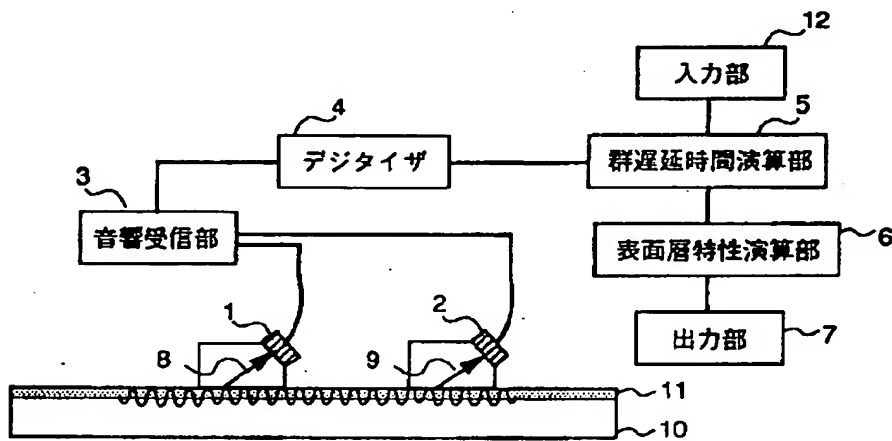
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DRAWINGS

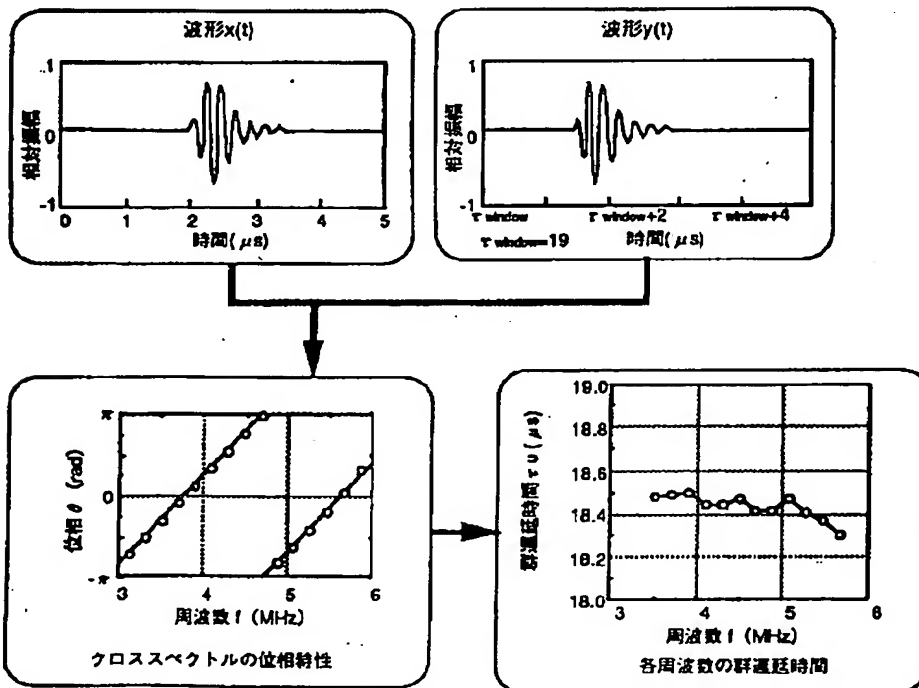
[Drawing 1]

【図 1】

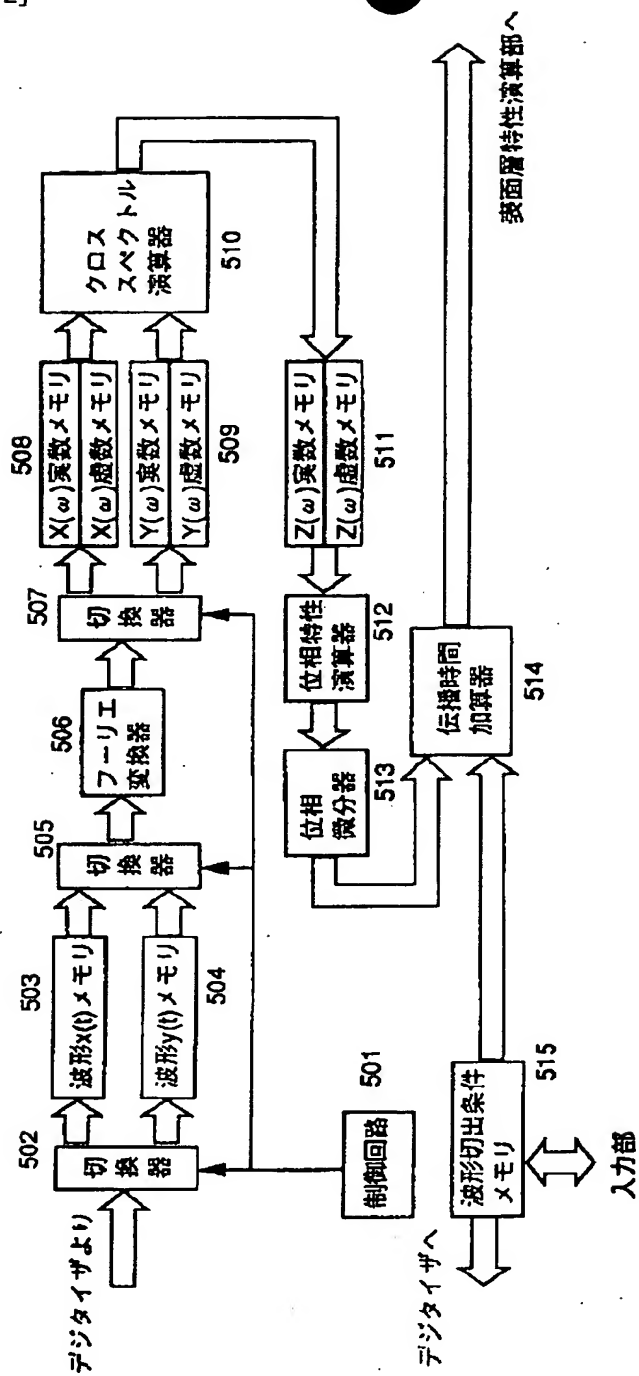


[Drawing 3]

【図 3】



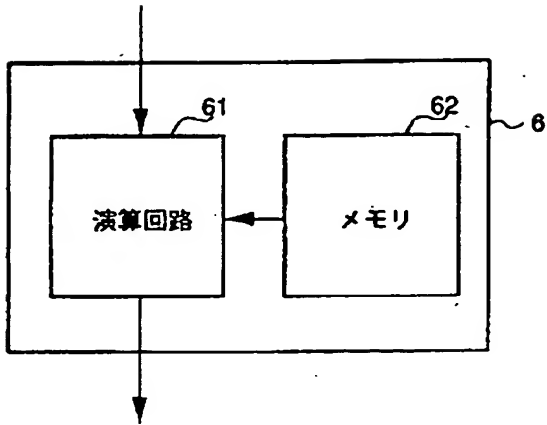
[Drawing 2]



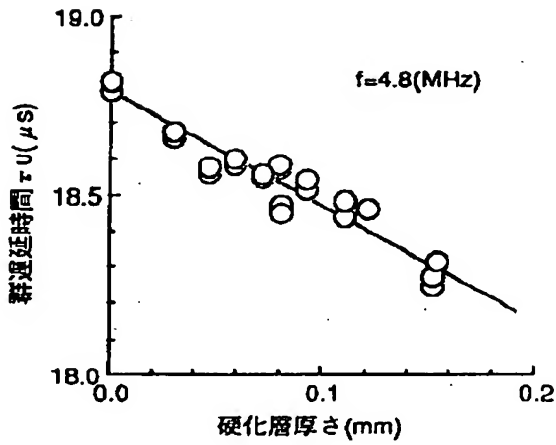
【図2】

[Drawing 4]

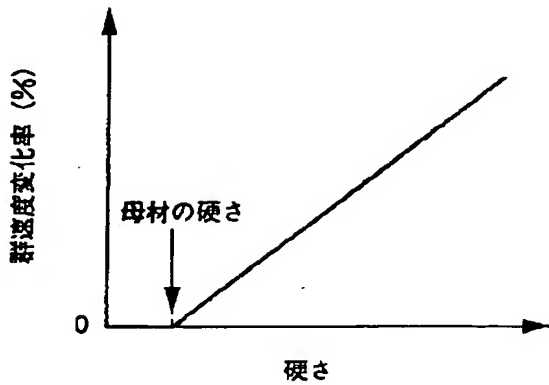
【図 4】



[Drawing 5]
【図 5】

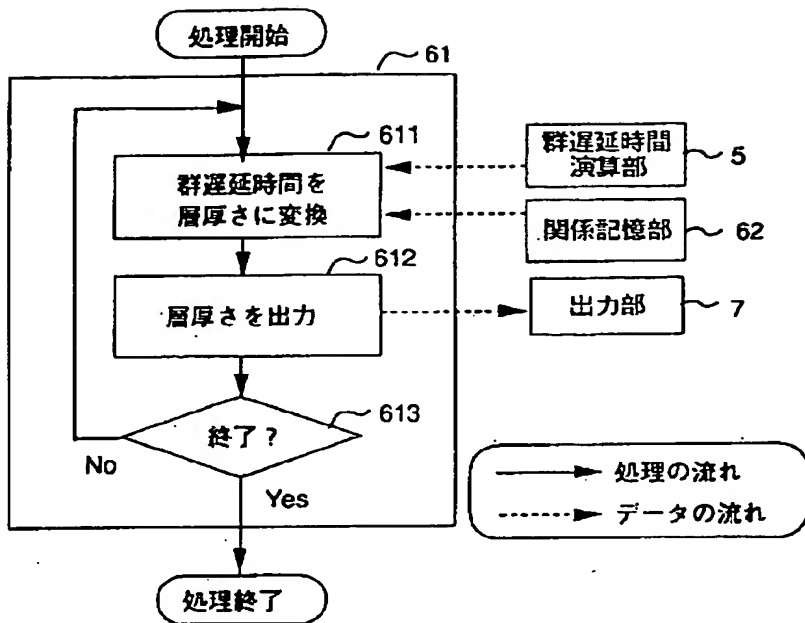


[Drawing 7]
【図 7】



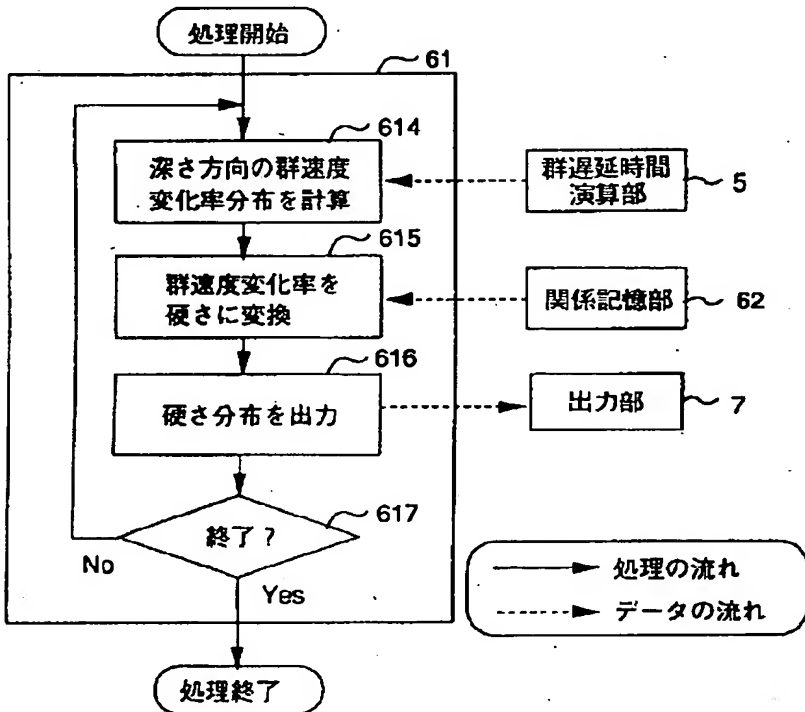
[Drawing 6]

【図 6】



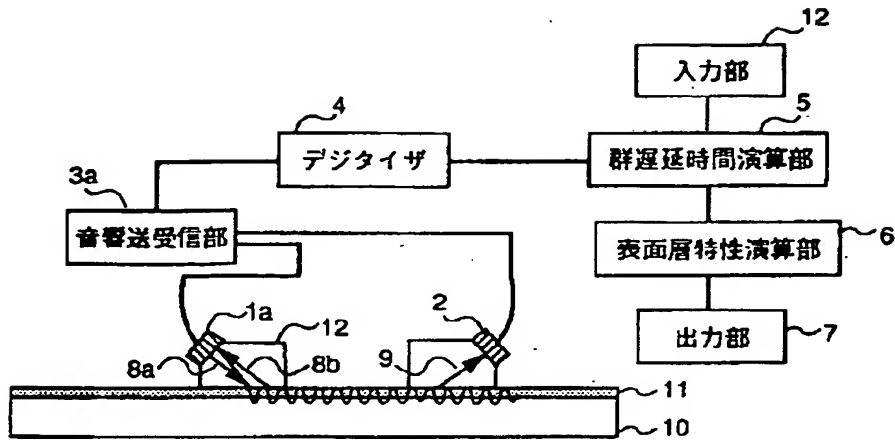
[Drawing 8]

【図 8】



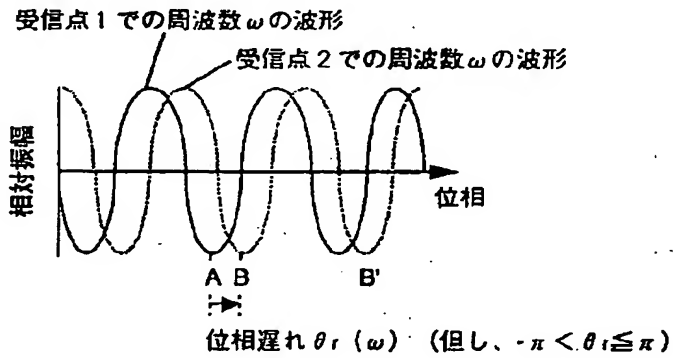
[Drawing 9]

【図 9】



[Drawing 10]

【図 10】



$$\text{位相差 } \theta(\omega) = \theta_r(\omega) + 2n\pi$$

(n は整数)

$$\text{位相遅延時間 } \tau_p(\omega) = \frac{\theta(\omega)}{\omega}$$

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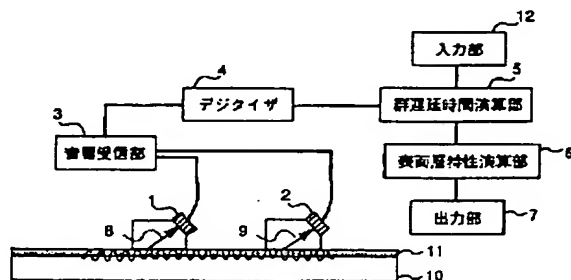
(54) 【発明の名称】 表面層特性の測定方法および装置

(57) 【要約】

【課題】 音響信号の伝播経路長が未知の場合においても、被検体の表面層の特性を測定できる方法および装置を提供する。

【解決手段】 鋼材10の表面に硬化層11が形成された面を伝播する表面波のうち、受信器1側に屈折する超音波8を受信器1で受信する。受信器2は受信器1から離れて配置し、受信器2側に屈折する超音波9を受信する。超音波8と超音波9は、電気信号に変換され、超音波探傷器等で構成される音響受信部3で増幅され、デジタルオシロスコープ等で構成されるデジタイザ4でデジタル信号に変換される。このデジタル信号を使って群遅延時間演算部5で超音波8と超音波9の複数周波数の群遅延時間を計算し、表面層特性演算部6で表面層の特性を計算する。

【図1】



【特許請求の範囲】

【請求項1】 被検体から受信した複数の音響信号から、該被検体の表面層の特性を測定する表面層特性測定方法において、

前記複数の音響信号の中の二つの音響信号間の任意の周波数の群遅延時間を求め、あらかじめ求めておいた群遅延時間と前記表面層特性との関係に基づいて、求められた前記二つの音響信号間の任意の周波数の群遅延時間を表面層特性に変換し、被検体の表面層の特性を測定することを特徴とする表面層特性の測定方法。

【請求項2】 前記あらかじめ求めておいた群遅延時間と表面層特性との関係が、群遅延時間から表面層の特性に変換する変換関数であることを特徴とする請求項1記載の表面層特性の測定方法。

【請求項3】 前記表面層特性が硬化層厚さであることを特徴とする請求項1または2記載の表面層特性の測定方法。

【請求項4】 前記表面層特性が表面層の物性の深さ方向分布であり、前記任意の周波数は複数の周波数であって、前記変換関数が前記複数の周波数の群遅延時間と前記物性の深さ方向分布とを深さ方向エネルギー分布によって関連づける変換関数であることを特徴とする請求項2記載の表面層特性測定方法。

【請求項5】 前記表面層特性が表面層の物性の深さ方向分布であり、前記任意の周波数は複数の周波数であって、前記変換関数が前記複数の周波数の群遅延時間と前記物性の深さ方向分布とを深さ方向音圧分布によって関連づける変換関数であることを特徴とする請求項2記載の表面層特性測定方法。

【請求項6】 前記表面層特性が表面層の物性の深さ方向分布であり、前記任意の周波数は複数の周波数であって、前記変換関数が前記複数の周波数の群遅延時間と前記物性の深さ方向分布とを深さ方向変位分布によって関連づける変換関数であることを特徴とする請求項2記載の表面層特性測定方法。

【請求項7】 前記表面層特性が表面層の硬さ分布であることを特徴とする請求項4ないし6のいずれか1項に記載の表面層特性測定方法。

【請求項8】 被検体から受信した複数の音響信号から、該被検体の表面層の特性を測定する表面層特性測定装置において、

前記被検体表面を伝播する音響信号を受信する音響受信手段と、

この音響受信手段で受信した複数の音響信号のうち異なる位置で受信した任意の二つの音響信号間の群遅延時間を算出する群遅延時間演算手段と、

この群遅延時間演算手段で演算した群遅延時間を該被検体の表面層特性に変換する表面層特性変換手段と、を備えていることを特徴とする表面層特性測定装置。

【請求項9】 前記音響受信手段が、音響信号を送信す

る手段を含んでなることを特徴とする特徴とする請求項8記載の表面層特性測定装置。

【請求項10】 前記表面層特性変換手段が、硬化層厚さと群遅延時間との関係が格納されたメモリと、このメモリに記憶された前記関係に基づいて前記群遅延時間から硬化層厚さを演算する演算回路とを含んでなることを特徴とする請求項8記載の表面層特性測定装置。

【請求項11】 前記表面層特性変換手段が、硬化層厚さと母材に対する音速変化率の関係が格納されたメモリと、このメモリに記憶された前記関係に基づいて前記群遅延時間から硬化層厚さを演算する演算回路とを含んでなることを特徴とする請求項8記載の表面層特性測定装置。

【請求項12】 前記表面層特性変換手段が、被検体の硬さと群速度変化率の関係が格納されたメモリと、このメモリに記憶された前記関係に基づいて前記群速度変化率から被検体表面の硬さ分布を演算する演算回路とを含んでなることを特徴とする請求項8記載の表面層特性測定装置。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、音響信号を使用して被検体表面層の特性を非破壊で測定する方法および装置に関する。

【0002】

【従来の技術】表面層の厚さ、もしくは表面層の性質（硬さ等）の深さ方向分布を非破壊で計測する方法として表面波の音速変化を利用する方法が知られている。この方法は、表面層の音響的性質すなわち表面層の弾性係数や密度が母材部と異なることを利用するものである。すなわち、表面波は被検体の表面から深さ方向に一波長の範囲内に90%以上のエネルギーが存在するため、表面層の厚さによって表面波の表面層と母材部を伝播する割合が変化する。この結果、表面層の厚さに応じて表面波の音速が変化するということになる。

【0003】この原理を用いた測定法として特開昭62-277554に開示された方法がある。この方法では、被検体表面に表面波を伝播させて一方でそれを受信し、その間の伝播時間から音速を求め、母材の音速を基準とした音速変化率から表面層の厚さを測定している。しかし、表面波では周波数によって音速が異なる分散現象により高周波のほうが低周波より速く伝播する現象が生じ、伝播に伴って変化したり広がったりする。このため、上記の方法では、高精度な伝播時間測定は困難である。

【0004】これを解決する手段として、周波数毎の伝播時間から音速を求める方法があり、この例として、非破壊検査（第39巻第2号pp. 99-103）「レーリ一波による表面層の非破壊評価」で発表された方法が知られている。この方法では、複数の周波数の位相速度

を計測し、その変化率から表面層の弾性係数の深さ方向分布を計算するようになっている。

【0005】

【発明が解決しようとする課題】ところで、上記従来技術では複数周波数の位相速度を計測するようになっているが、これには、2受信点間の位相遅延時間の測定が必要となる。位相遅延時間は前記2受信点で受信した両受信波について、ある周波数成分の位相差から算出する。

$$\theta(\omega) = \theta_r(\omega) + 2n\pi$$

と表現できる。一方、位相遅延時間 $\tau_p(\omega)$ は、

$$\tau_p(\omega) = \theta(\omega) / \omega$$

で算出されるため、やはり、 $2n\pi$ の任意性の影響を受ける。このために、この問題を別の手段で解決する必要がある。

【0006】そこで、前記後者の公知例では、母材の状態と表面層が形成された状態では受信波間の位相差に $2n\pi$ 以内の差しか生じないと前提から、既知の母材の音速と伝播経路長からおおよそその位相差を求め、その位相差からの $-\pi \sim \pi$ の間のずれのみを計測によって求める手段を採用している。しかしながら、送信や受信の位置が不安定である場合や伝播経路が曲面である場合など、伝播経路長が測定困難な場合には、前記手段によりおおよそその位相差を知ることができず、ひいては表面層の弾性係数(硬さ)の測定が困難になる。

【0007】本発明は、このような従来技術の実情に鑑みてなされたもので、その目的は、伝播経路長が未知であっても、表面層の特性を測定できる方法および装置を提供することにある。

【0008】

【課題を解決するための手段】上記目的を達成するため、第1の手段は、被検体から受信した複数の音響信号から、該被検体の表面層の特性を測定する表面層特性測定方法において、前記複数の音響信号の中の二つの音響信号間の任意の周波数の群遅延時間を求め、あらかじめ求めておいた群遅延時間と前記表面層特性との関係から、前記二つの音響信号間の任意の周波数の群遅延時間を表面層特性に変換し、被検体の表面層の特性を測定することを特徴としている。

【0009】この場合、前記あらかじめ求めておいた群遅延時間と表面層との特性の関係として、例えば群遅延時間から表面層の特性に変換する変換関数を導入し、表面層特性として硬化層厚さを測定する。

【0010】また、前記表面層特性として表面層の物性の深さ方向分布を測定する場合、前記任意の周波数は複数の周波数であって、前記変換関数として前記複数の周波数の群遅延時間と前記物性の深さ方向分布とを深さ方向エネルギー分布によって関連づける変換関数を導入し、表面層特性として表面層の硬さ分布を測定する。

【0011】また、前記エネルギー分布に代えて音圧分布あるいは変位分布を導入することもできる。

この過程を図10を参照して説明する。同図において、受信点1での角周波数 ω の波形に対し、受信点2での角周波数 ω の波形は、 $\theta_r(\omega)$ の位相遅れがあるとす。しかし、実際には受信点1の谷Aが受信点2の谷Bであるか谷B'であるか、あるいは 2π の整数倍離れた他の谷であるは明らかでない。すなわち、位相差 $\theta(\omega)$ には $2n\pi$ (n は整数)の任意性が存在し、位相差 $\theta(\omega)$ は、

$$\dots (1)$$

$$\dots (2)$$

【0012】第2の手段は、被検体から受信した複数の音響信号から、該被検体の表面層の特性を測定する表面層特性測定装置において、前記被検体表面を伝播する音響信号を受信する音響受信手段と、この音響受信手段で受信した複数の音響信号のうち異なる位置で受信した任意の二つの音響信号間の群遅延時間を算出する群遅延時間演算手段と、この群遅延時間演算手段で演算した群遅延時間を該被検体の表面層特性に変換する表面層特性変換手段とを備えていることを特徴としている。

【0013】この場合、前記音響受信手段が音響信号を送信する手段を含み、両機能を兼ねるように構成することもできる。

【0014】また、前記表面層特性変換手段を、硬化層厚さと群遅延時間との関係が格納された関係記憶部と、この関係記憶部に記憶された前記関係に基づいて前記群遅延時間から硬化層厚さを演算する演算回路とを含んで構成したり、硬化層厚さと母材に対する音速変化率の関係が格納された関係記憶部と、この関係記憶部に記憶された前記関係に基づいて前記群遅延時間から硬化層厚さを演算する演算回路とを含んで構成したり、被検体の硬さと群速度変化率の関係が格納された関係記憶部と、この関係記憶部に記憶された前記関係に基づいて前記群遅延時間から被検体表面の硬さ分布を演算する演算回路とを含んでそれぞれ構成できる。

【0015】このように構成すると、群遅延時間は位相を角周波数で微分した値であるため、位相の $2n\pi$ の任意性に関係なく算出することができるようになる。これによって、伝播経路長を測定する等の解決手段を導入する必要がなくなる。

【0016】また、表面層特性を求める変換関数を、複数の周波数の相対群遅延時間と相対群速度の深さ方向分布を音響信号の深さ方向エネルギー分布によって関連づける計算式と、群速度変化率と表面層の物性値を関連づける関数とすると、深さ方向エネルギー分布は既知であるので、この計算式の逆変換により相対群速度の深さ方向分布を算出することができる。相対群速度は深さ方向の最深部で母材の群速度に一致し、各層の母材群速度に対する群速度変化率が算出できる。次に、この群速度変化率を前記関係に基づいて表面層の物性値に変換する。

なお、ここで相対というのは、伝播経路長が未知である（計算に伝播経路長を使用していない）ので、速度そのものを算出しているわけではないからである。

【0017】

【実施例】以下、図面を参照し、本発明の一実施形態について説明する。

【0018】図1に、伝播モードが表面波の超音波を使用し、鋼材表面に形成した硬化層の特性を測定する表面層特性測定装置の概略構成を示す。

【0019】同図において、層厚さ測定装置は、受信器1と、受信器2と、音響受信部3と、デジタイザ4と、群遅延時間演算部5と、表面層特性演算部6と、出力部7とを備えている。

【0020】図1において、鋼材10の表面に硬化層11が形成された面を伝播する表面波のうち、受信器1は当該受信器1側に屈折した超音波8を受信し、受信器1から離れて配置された受信器2は当該受信器2側に屈折した超音波9を受信する。超音波8と超音波9は電気信号に変換され、超音波探傷器等で構成される音響受信部3で増幅され、デジタルオシロスコープ等で構成されるデジタイザ4で各々デジタル信号の波形 $x(t)$ と $y(t)$ に変換される。このデジタル信号はデジタイザ4中で、超音波8についてはある時刻から一定幅の時間区間（以下、「時間窓」と称する）のデジタル信号の波形 $x(t)$ として保持され、超音波9については $x(t)$ と異なってもよい時刻から始まる時間窓のデジタル信号の波形 $y(t)$ として保持される。なお、時間窓の切り出しはオペレータが指定してもよいが、超音波8と超音波9の現われるおおよその時間がわかっているならば、予め遅延時間を固定した時間窓を用意してもよい。

【0021】群遅延時間演算部5では、前記波形 $x(t)$ と波形 $y(t)$ の複数周波数の群遅延時間 $\tau_{ij}(\omega)$ （ ω は超音波の角周波数）を計算し、表面層特性演算部6で表面層の特性を計算する。計算された結果は、出力部7で出力される。また、時間窓の切り出し位置や幅は入力部12から入力される。なお、受信器1と

$$\tau_{ij}(\omega) = d\theta(\omega) / d\omega + \tau_{\text{window}} \quad \dots (3)$$

で表される。この式(3)から群遅延時間 $\tau_{ij}(\omega)$ は、前記 $2n\pi$ が要素として含まれないのでクロススペクトルの位相 $\theta(\omega)$ に $2n\pi$ の任意性があっても算出可能であることがわかる。

【0024】表面層特性演算部6は、図4に示すように演算回路61とメモリ62を有する。この例は、硬化層の特性として硬化層の厚さを測定する例である。前記メモリ62には、硬化層厚さと群遅延時間の関係があらかじめ格納されている。この関係の一例として、発明者らが図1の装置構成の下に、受信器1と受信器2との距離を約57mmとして行なった実験結果の例を図5に示す。同図は、硬化層厚さと4.8MHzの表面波の群遅延時間の関係を示しており、この図では硬化層厚さが厚

受信部2は同一の受信器でもよい。しかし、その場合には、受信器の位置を変えて、異なる位置で表面波を受信する必要がある。

【0022】群遅延時間演算部5の一構成例と各部の機能について図2を参照して説明する。制御回路501は切換器502を制御してデジタイザ4から図3に示すような波形 $x(t)$ と波形 $y(t)$ を読み出し、それぞれ波形 $x(t)$ メモリ503、波形 $y(t)$ メモリ504に記憶する。次に、制御回路501は、切換器505を制御して波形 $x(t)$ メモリ503と波形 $y(t)$ メモリ504から、波形を読み出してフーリエ変換器506に波形を送り、フーリエ変換器506で波形 $x(t)$ と波形 $y(t)$ をフーリエ変換させる。フーリエ変換された波形 $x(t)$ 、 $y(t)$ は、さらに、制御回路501によって制御される切換器507によって選択される $X(\omega)$ メモリ508と $Y(\omega)$ メモリ509に各々記憶される。次に、 $X(\omega)$ メモリ508と $Y(\omega)$ メモリ509に記憶された波形データに基づいてクロススペクトル演算器510で $X(\omega)$ と $Y(\omega)$ のクロススペクトルを算出し、演算結果を $Z(\omega)$ メモリ511に記憶する。なお、 $X(\omega)$ メモリ508、 $Y(\omega)$ メモリ509および $Z(\omega)$ メモリ511はそれぞれ実数メモリと虚数メモリからなっている。 $Z(\omega)$ メモリ511に記憶されたクロススペクトルは位相特性演算器512入力され、クロススペクトルの位相特性 $\theta(\omega)$ （図3参照）が算出される。算出された移送特性 $\theta(\omega)$ は、位相微分器513で微分され、遅延時間が求められる。伝播時間加算器514は、位相微分器513で求められた遅延時間と波形切出条件メモリ515から読み出された時間窓間の遅延時間 τ_{window} を加算する。加算された結果、すなわち群遅延時間 $\tau_{ij}(\omega)$ は、表面層特性演算部6に送られる。

【0023】以上の機能の中で、クロススペクトルの位相特性 $\theta(\omega)$ から群遅延時間 $\tau_{ij}(\omega)$ を求める手続きは、

くなるほど群遅延時間が短くなっている。すなわち、群速度は硬化層厚さが厚いほど速くなる傾向にあることがわかる。このことから、厚さが既知の複数種類の試験片を使用してこの関係を求め、校正曲線として用いることで、逆に群遅延時間から硬化層厚さを求めることができる。なお、メモリ62に記憶する硬化層厚さと群遅延時間の関係は、複数周波数について記憶しておき、必要な周波数の関係をメモリ62から参照してもよい。このときの周波数は、硬化層の厚さと波長のオーダが一致する程度の周波数とし、その周波数域の振幅が大きい探触子を用いるのが望ましい。

【0025】なお、メモリ62に記憶するデータは、硬化層厚さと母材に対する音速変化率の関係でもよい。ま

た、受信器を3個以上用意して、任意の2個の受信器で受信した超音波の群遅延時間を求め、同様の処理を行なってもよい。

【0026】このように本実施形態では、式(3)から算出する群遅延時間 $\tau_g(\omega)$ を表面層の特性に変換するので、クロススペクトルの位相 $\theta(\omega)$ に $2n\pi$ の任意性があっても算出可能であり、これによって前述の位相遅延時間のように位相の $2n\pi$ の n の値を求める必要や、位相遅延時間の計測条件、例えば、伝播経路長を正確に測定する機能や、母材の状態と表面層が形成された状態では受信波間の位相差に $2n\pi$ 以内の差しか生じないとの計測条件などが不要となり、測定過程や装置構成を簡略化することができる。

【0027】ここで、表面層特性演算部6の演算回路61の硬化層の特性(厚さ)を測定するときの具体的処理内容について説明する。図6は表面層特性演算部6の処理とデータの流れの関係を示すフローチャートである。

【0028】この処理では、処理開始後、ステップ611で群遅延時間演算部5から群遅延時間 $\tau_g(\omega)$ を読み込み、さらに、メモリ(関係記憶部)62から硬化層の厚さと群遅延時間の関係を読み込んで、この関係から群遅延時間を厚さに変換する。次いで、ステップ612で群遅延時間 $\tau_g(\omega)$ から変換された硬化層の厚さを出力部7に出力し、ステップ613で処理終了か否かの問い合わせを行ない、終了でなければステップ611に戻る。なお、ステップ611でメモリ(関係記憶部)62から読み込むデータは、硬化層の厚さと音速変化率の関係でもよい。

$$V(\omega_k) = \sum (P_k U_k)$$

(ただし、 $\sum P_k = 1$)が成立する。なお、エネルギー分布の代わりに、音圧分布、変位分布等を用いてもよ

$$V = P U$$

と表される。ここで、 V は角周波数 ω_k ($k=1 \sim n$)の群速度を表わす $n \times 1$ 行列、 U は計算層 k ($k=1 \sim n$)の群速度を表わす $n \times 1$ 行列、 P は角周波数 ω_k ($k=1 \sim n$)のエネルギー分布を表わす $n \times n$ 行列で

$$U = P^{-1} V$$

で求められる。

【0032】しかし、ここでは伝播距離 L が正確に測定できていないために、各周波数の群速度 V は未知係数 L を含む。したがって、計算層の群速度 U も未知係数 L に依存する。しかしながら、計算層のなかで最深の計算層

$$\{(U_k - U_n) / U_n\} * 100$$

(ただし、 $k=1 \sim n$)で与えられる。

【0033】以上の手続きにより、ステップ614では深さ方向の群速度変化率分布を算出する。次に、ステップ615で、メモリ(関係記憶部)62から群速度変化率と硬さの関係を読み込み、群速度変化率を硬さに変換する。そして、ステップ616で出力部7に硬化層厚さを出力し、ステップ617で処理終了か否かの問い合わせ

【0029】次に、硬化層の硬さが、連続的に母材の硬さに近づく場合(実際、硬化層はこのような性質を示すことが多い)に有効な方法について説明する。

【0030】図4に示す表面層特性演算部6は、硬化層の特性として硬化層の深さ方向分布を測定する場合には、次のように構成することができる。すなわち、メモリ62には、図7に示すような硬さと群速度変化率の関係を格納しておく。この関係は、硬さが既知な試験片等を用いて予め測定しておく必要がある。また、演算回路61は、群速度変化率を硬さに変換する演算機能を有する。

【0031】ここで、演算回路61での具体的処理例について説明する。図8は、演算回路61の処理とデータの流れを示すフローチャートである。処理開始後、ステップ614で群遅延時間演算部5から、 n 個の複数周波数の群遅延時間 $\tau_g(\omega_k)$ ($k=1 \sim n$)を読み込む。ここで、被検体の表面近傍を計算のための擬似的な層(以下、「計算層」と称する)に分割し、各層の群速度を浅い方から順に U_1 から U_n とおく。ここで、計算層は、硬化層の硬さが母材の硬さと同等となる深さまで仮定する。表面波のエネルギー分布は、表面下一波長の範囲内にエネルギーの90%以上が分布し、そのエネルギー分布は指数関数的に変化することが理論的に知られている(佐藤泰夫著 弾性波動論 PAGA88)。このため、ある波長の群速度 $V(\omega)$ が、各計算層のエネルギー分布 P_k と群速度 U_k から重み平均的に算出できると仮定すれば、

$$\dots (4)$$

い。式(4)を全計算層に関して表現すると、

$$\dots (5)$$

ある。エネルギー分布 P は理論より既知であるので、角周波数 ω_k ($k=1 \sim n$)の群速度 V を測定すれば、計算層の群速度 U は、

$$\dots (6)$$

n は母材と同程度の群速度を示すと推定できるので、ここの群速度 U_n を用いて未知係数 L によらない値として群速度変化率を計算する。各計算層の群速度変化率(%)は、

$$\dots (7)$$

せを行ない、終了でなければステップ614に戻る。

【0034】ここでは、硬さ分布を求めたが、ある硬さをしきい値として、そのしきい値硬さまでを硬化層と定義すれば、ステップ615において、硬さ分布から硬化層厚さを容易に求めることができる。

【0035】このように本実施形態によれば、測定毎に最深の計算層の群速度を基準(母材の群速度)として、

深さ方向の群速度変化率分布を求めるので、探触子を測定毎に任意の距離に配置できる。したがって、被検体表面の凹凸により、音響信号の被検体への入射点や出射点の位置が不安定な場合や、伝播経路が曲面である場合においても測定が可能になる。

【0036】なお、上記実施形態においては、表面層の特性を表面層の厚さ、あるいは表面層の硬さ分布として説明したが、原理的には群速度の変化率を指標として二次的に特性を評価する方法なので、硬さの他にも密度、弾性係数、残留応力など群速度変化率と相関がある特性であれば、同様の方法および装置により、その特性を測定可能である。

【0037】次に、他の実施形態について説明する。この実施形態は、被検体表面に能動的に表面波を発生させる必要がある場合の例であり、その概略構成を図9に示す。

【0038】同図において、層厚さ測定装置は、送受信器1aと、受信器2と、音響送受信部3aと、デジタイザ4と、群遅延時間演算部5と、表面層特性演算部6と、出力部7とを備えている。この層厚さ測定装置では、超音波探傷器等で構成される音響送受信部3aからの送信パルスを受けて、送受信器1aから超音波8aが送信される。超音波8aは、鋼材10との境界面で表面波にモード変換し、モード変換した表面波はくさび12の端部で反射し、再びくさび内に屈折する超音波8bと、端部を通過して別の受信器2で受信される超音波9とに分かれ、これらをそれぞれ受信して前述の実施形態と同様の各部によって同様に処理される。

【0039】このように構成すると、新たに音響送信器を用意する必要がなくなるので、装置構成を簡単に行うことができる。

【0040】

【発明の効果】本発明によれば、位相遅延時間のように位相の $2n\pi$ の n の値を求める方法、機能もしくは計測条件が不要となるので、測定過程や装置構成を簡略化することができる。

【0041】また本発明によれば、探触子を測定毎に任意の距離に配置できる。したがって、被検体表面の凹凸により、音響信号の被検体への入射点の出射点の位置が不安定な場合や、伝播経路が曲面である場合においても

測定が可能になる。

【0042】更に本発明によれば、被検体表面に能動的に表面波を発生させる必要がある場合でも、新たに音響送信器を用意する必要がなく、装置構成が簡単になる。

【図面の簡単な説明】

【図1】本発明の実施形態に係る表面層特性の測定装置の概略構成図である。

【図2】図1における群遅延時間演算部の構成を示すブロック図である。

【図3】図1における群遅延時間演算部における群遅延時間の計算過程を示す説明図である。

【図4】図1における表面層特性演算部の構成を示すブロック図である。

【図5】硬化層厚さに対する群遅延時間の変化を示す説明図である。

【図6】図4における表面層特性演算部の処理手順を示すフローチャートである。

【図7】硬さに対する群速度変化率の変化を示す説明図である。

【図8】図4における表面層特性演算部の他の処理手順を示すフローチャートである。

【図9】本発明の他の実施形態に係る表面層特性の測定装置の概略構成図である。

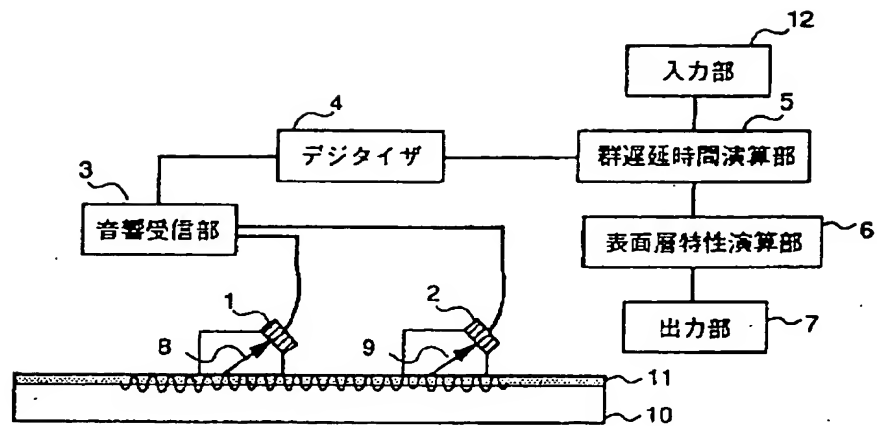
【図10】位相遅延時間の $2n\pi$ の任意性を示す説明図である。

【符号の説明】

- 1 受信器
- 2 受信器
- 3 音響受信部
- 4 デジタイザ
- 5 群遅延時間演算部
- 6 表面層特性演算部
- 7 出力部
- 8 超音波
- 9 超音波
- 10 鋼材
- 11 硬化層
- 12 入力部
- 61 演算回路
- 62 メモリ（関係記憶部）

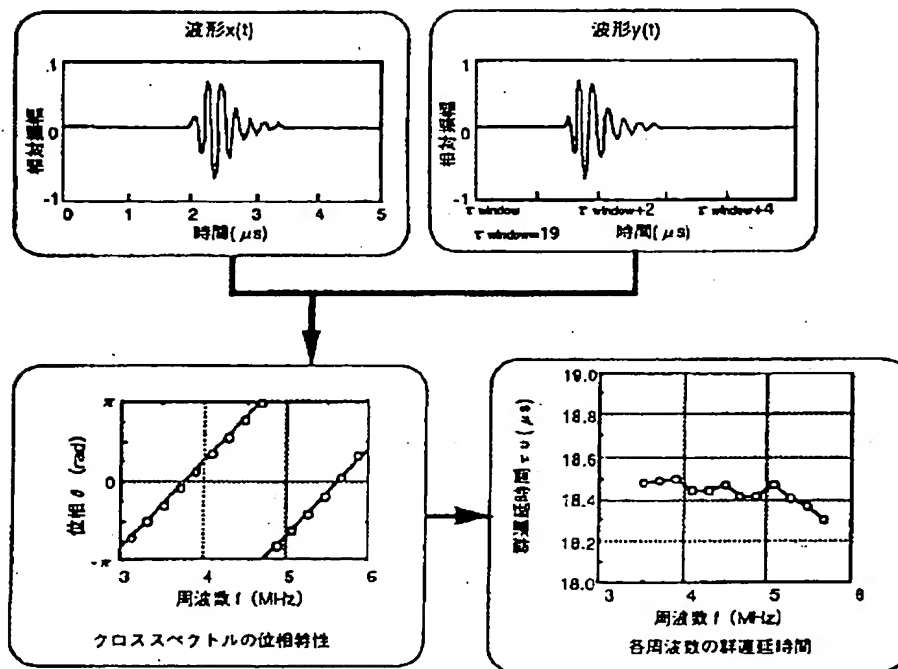
【図1】

【図1】

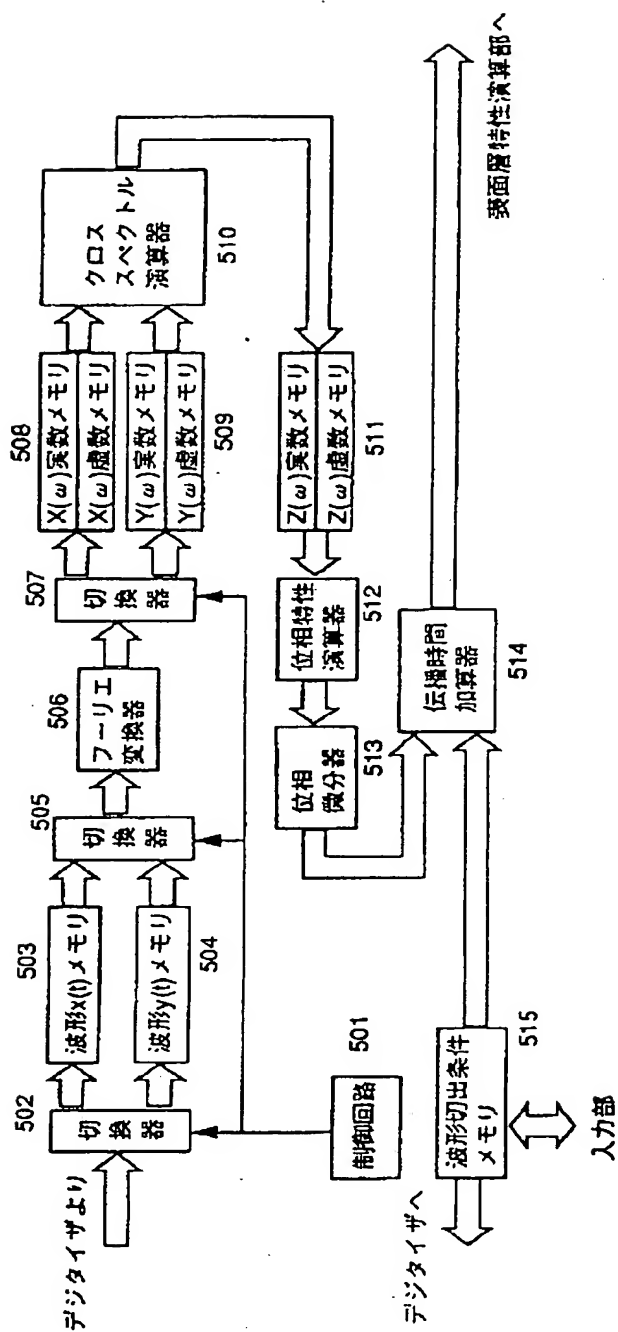


【図3】

【図3】

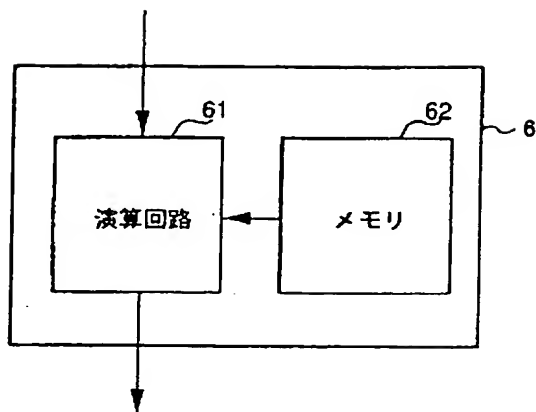


【图2】



【図4】

【図4】

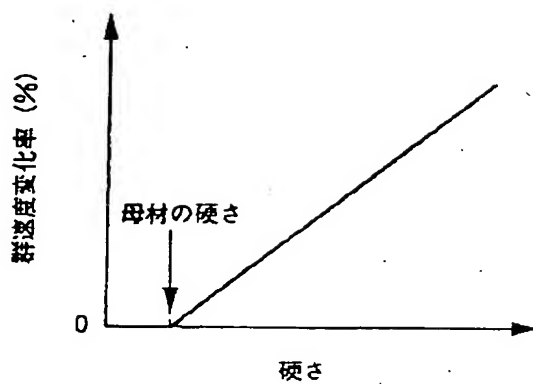
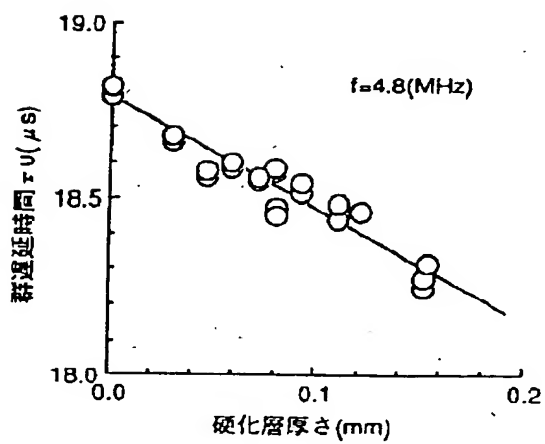


【図5】

【図7】

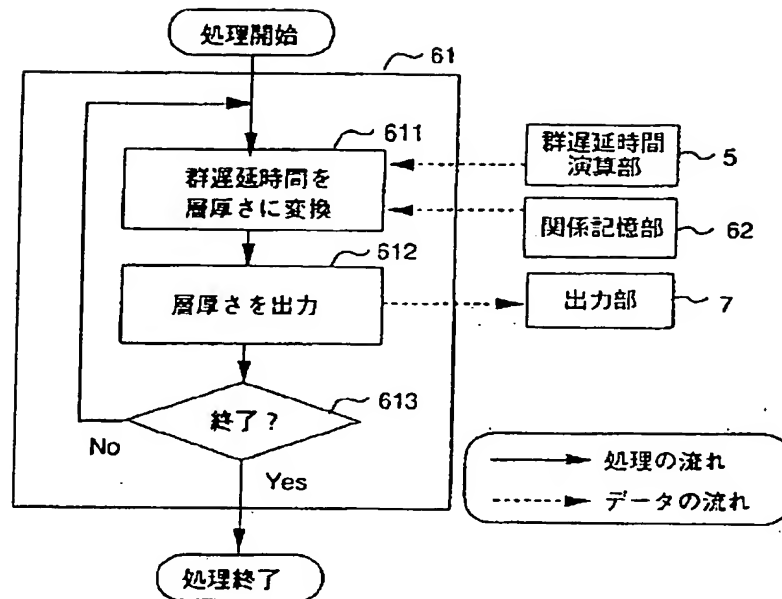
【図5】

【図7】



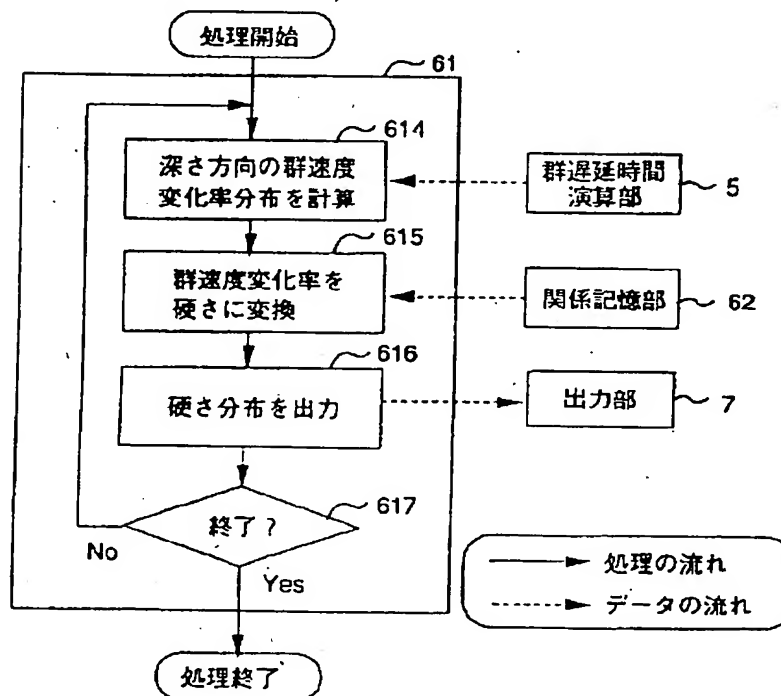
【図6】

【図6】



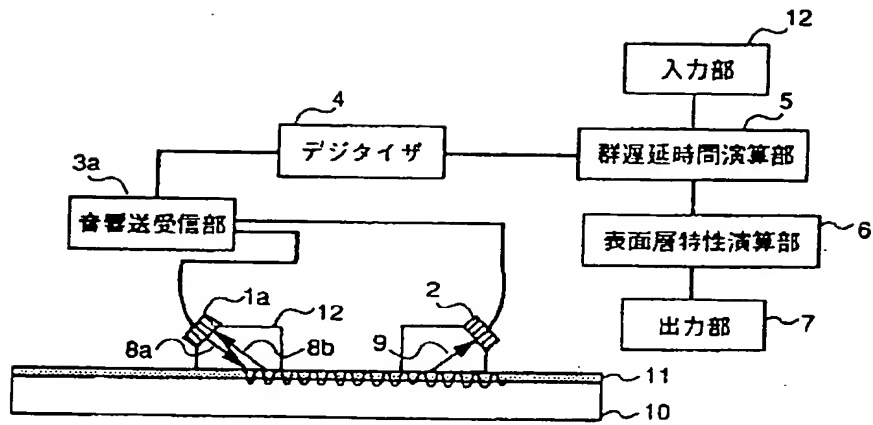
【図8】

【図8】



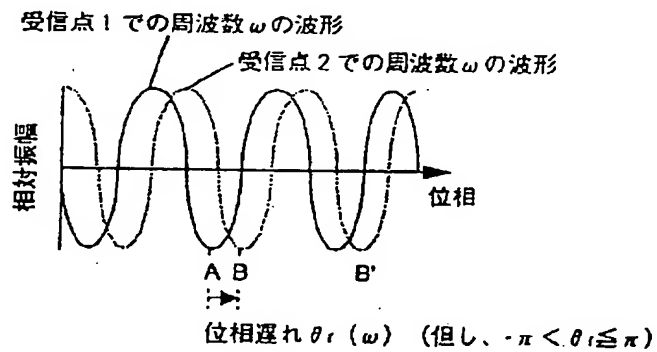
【図9】

【図9】



【図10】

【図10】



$$\text{位相差 } \theta(\omega) = \theta_r(\omega) + 2n\pi$$

(n は整数)

$$\text{位相遅延時間 } \tau_p(\omega) = \frac{\theta(\omega)}{\omega}$$

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【FI】

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【手続補正2】

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【補正対象項目名】0010

【補正方法】削除

【手続補正3】

【補正対象書類名】明細書

【補正対象項目名】0011

【補正方法】削除